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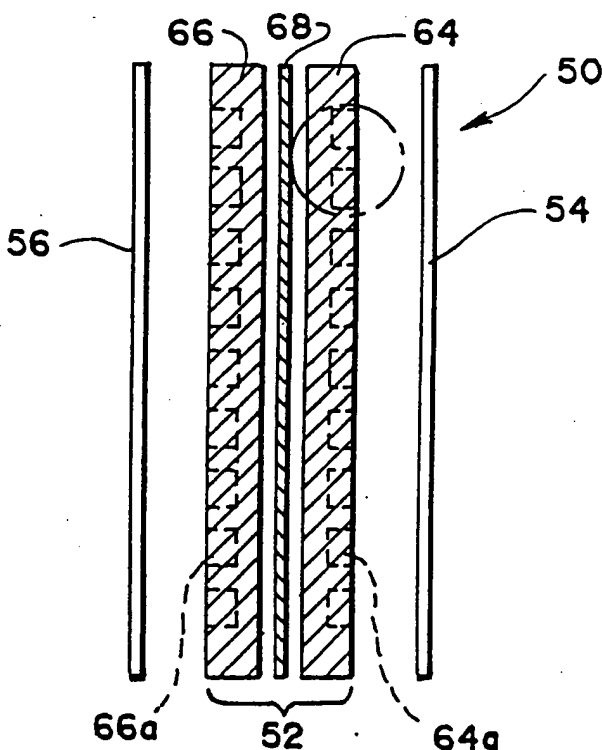
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁵ : H01M 2/00	A1	(11) International Publication Number: WO 94/09519 (43) International Publication Date: 28 April 1994 (28.04.94)
<p>(21) International Application Number: PCT/US92/07755</p> <p>(22) International Filing Date: 20 October 1992 (20.10.92)</p> <p>(71) Applicant: BALLARD POWER SYSTEMS [CA/CA]; 980 West 1st Street, Unit 107, North Vancouver, British Columbia V7P 3N4 (CA).</p> <p>(71)(72) Applicants and Inventors: WILKINSON, David, P. [CA/CA]; 1391 Coleman Street, North Vancouver, British Columbia V7K 1W4 (CA). VOSS, Henry, H. [CA/CA]; 524 West 28th Street, North Vancouver, British Columbia V7N 2J5 (CA). PRATER, Keith [US/CA]; 7049 Prescott Street, Vancouver, British Columbia V6N 1N2 (CA).</p>		<p>(74) Agent: REYNOLDS, Donald, P.; McAndrews, Held & Malloy, Ltd., Northwestern Atrium Center, 500 West Madison Street, Suite 3400, Chicago, IL 60661 (US).</p> <p>(81) Designated States: AU, CA, JP, KR, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, SE).</p> <p>Published With international search report.</p>

(54) Title: LIGHTWEIGHT FUEL CELL MEMBRANE ELECTRODE ASSEMBLY WITH INTEGRAL REACTANT FLOW PASSAGES

(57) Abstract

An electrochemical fuel cell is provided for converting a fuel reactant stream and an oxidant reactant stream to a reaction product stream and electrical energy. The fuel cell includes a membrane electrode assembly (52) interposed between two separator layers (54, 56). The separator layers are formed of thin electrically conductive sheet material which is substantially impermeable to the fuel and oxidant reactant streams. The membrane electrode assembly comprises first and second electrode layers (64, 66) formed of porous electrically conductive sheet material. The electrode layers have a catalyst associated therewith, and an ion exchange membrane is interposed between the first and second electrode layers. The electrode layers include passages, such as the interstitial spaces within the electrode material or grooves (64a, 66a) formed in the surface of the electrode material, for flowing a reactant stream between an inlet and outlet within the electrode layer.



LIGHTWEIGHT FUEL CELL MEMBRANE ELECTRODE
ASSEMBLY WITH INTEGRAL REACTANT FLOW PASSAGES

FIELD OF THE INVENTION

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The present invention relates to electrochemical fuel cells employing solid polymer ion exchange membranes. More particularly, the present invention relates to a membrane electrode assembly for electrochemical fuel cells in which the reactant flow passages are integral with the electrode material. The present invention permits the construction of lightweight, low volume fuel cells having favorable power output characteristics.

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BACKGROUND OF THE INVENTION

Electrochemical fuel cells generate electrical energy by converting chemical energy derived from a fuel directly into electrical energy by the oxidation of the fuel in the cell. A typical fuel cell includes an anode, a cathode and an electrolyte. Fuel and oxidant are supplied to the anode and cathode, respectively. At the anode, the fuel permeates the electrode material and reacts at the catalyst layer to form cations, which migrate through the electrolyte to the cathode. At the cathode, the oxygen-containing gas supply reacts at the catalyst layer to form anions. The anions formed at the cathode react with the cations to form a reaction product. The fuel cell generates a useable electric current and the

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polytetrafluoroethylene. The MEA contains a layer of catalyst at each membrane/electrode interface to induce the desired electrochemical reaction. A finely divided platinum catalyst is typically employed.

In conventional fuel cells, the MEA is disposed between two rigid, electrically conductive separator plates, each of which has at least one flow passage or groove engraved, milled or molded in the surface facing the MEA. These separator plate, sometimes referred to as flow field plates, are typically formed of graphite. The flow passages in the separator plates direct the fuel and oxidant to the respective electrodes, namely, the anode on the fuel side and the cathode on the oxidant side. The separator plates are electrically coupled in series to provide a path for conducting electrons between the electrodes.

In conventional single cell arrangements, separator plates are located on both the anode and cathode sides of each individual fuel cell. The separator plates intimately contact the respective electrodes to provide a conductive path to carry electrons formed at the anode to the cathode to complete the electrochemical reaction. The separator plates thus perform several functions: (1) they act as current collectors, (2) they provide mechanical support for the electrodes, (3)

hydrogen and oxygen within the fuel cells. The stack also generally includes exhaust manifolds or outlets for expelling unreacted fuel carrying entrained water and for expelling unreacted oxidant carrying entrained water, as well as an outlet manifold for the coolant water exiting the stack.

Perfluorosulfonic ion exchange membranes, such as those sold by DuPont under its Nafion trade designation, have been found effective for use in electrochemical fuel cells. Nafion membranes must be hydrated with water molecules for ion transport to occur. Such hydration typically occurs by humidifying the fuel and oxidant streams prior to introducing the streams into the cell.

A new type of experimental perfluorosulfonic ion exchange membrane, sold by Dow under the trade designation XUS 13204.10, has also been found effective for use in electrochemical fuel cells. Like Nafion membranes, the Dow experimental membranes appear to require some hydration to effect hydrogen ion transport.

In fuel cells employing hydrogen as the fuel and oxygen as the oxidant, the fuel can be supplied in the form of substantially pure hydrogen or as a hydrogen-containing reformat, as, for example, the product of the reformation of methanol and water or reformation of natural gas.

Similarly, the oxidant can be supplied in the form

channels. Alternatively, the membrane electrode assembly itself could be formed with coolant channels or capillaries, such as, for example, tubes running through the electrode sheet material for carrying the coolant through the assembly, thereby eliminating the need for a separate coolant jacket. In addition, cooling could be accomplished by the passage of a coolant fluid, such as air, over heat transfer surfaces such as fins projecting from the separator plates.

The "repeating unit" of a fuel cell stack is the smallest recurring portion of the stack which includes at least one membrane electrode assembly, as well as the separator plates and the cooling jacket(s) associated with the membrane electrode assembly. Since one cooling jacket may not be present for each membrane electrode assembly (i.e., a cooling jacket could in some instances provide cooling to multiple membrane electrode assemblies), a repeating unit may include more than one membrane electrode assembly.

Conventional repeating units, which comprise membrane electrode assemblies interposed between two rigid separator plates generally formed of graphite, are disadvantageous in several respects. First, the separator plates, must be formed thick enough to accommodate engraved, milled or molded flow passages. The thickness of the

conventional fuel cells.

5 An additional benefit of the present design is the proximity of the reactant (fuel and oxidant) flow to the catalyst sites. Because the reactants flow through passages in the electrode material itself, as opposed to channels in the separator plate adjacent the electrode, the reactants need not migrate through the entire thickness of the electrode material to reach the catalyst layers. Decreasing the distance through which the reactants must travel to reach the catalyst layer enhances the access of the reactants to the catalyst layer and improves potential fuel cell performance.

15 Another advantage of the present invention over conventional fuel cell designs is the relative ease of forming flow passages in the electrode material as opposed to engraving, milling or molding passages in the rigid separator plates. Electrodes are generally composed of porous electrically conductive sheet material such as carbon fiber paper, while the rigid separator plates are generally formed of graphite or suitable metal. In the present invention, the rigid separator plates need not be engraved, milled or molded, but can be replaced by thin, lightweight sheets of nonporous electrically conductive material, which can be processed using less time

inlet and the oxidant stream outlet.

In one embodiment, the flow means comprises the interstitial spaces within at least one of the first and second electrode layers. The electrode layers can further comprise dam members for diverting the flow of the reactant stream within the electrode layer. The electrode layers can also comprise capillaries for conducting the reactant stream within the electrode layer along at least a portion of the distance between the inlet and the outlet. Such capillaries can be continuous or discontinuous and have openings at periodic intervals to permit the flow of reactant into the electrode and toward the catalyst layer.

In another embodiment of the electrochemical fuel cell, the electrode layers have at least one groove formed in the surface thereof facing away from the membrane. The surface of the adjacent separator layer facing the electrode layer is substantially planar. The grooved surface of the electrode layer and the planar surface of the adjacent separator layer cooperate to define a passage for the flow of the reactant stream within the electrode layer. In each electrode, the groove can be continuous, interconnecting the reactant inlet and the reactant outlet. The groove can also comprise a first groove extending from the reactant inlet and a

The coolant layer can also be formed with at least one groove formed in the surface thereof facing the membrane electrode assembly where the surface of the adjacent separator layer facing the coolant layer is substantially planar. In such a configuration, the grooved surface of the coolant layer and the planar surface of the adjacent separator layer cooperate to define a passage for the flow of coolant within the coolant layer. The preferred coolant fluid in this configuration is water, but other suitable coolant fluids such as ethylene glycol or air could also be employed.

Cooling of the membrane electrode assembly may also be accomplished by including the means for flowing a coolant fluid within at least one of the electrode layers such that heat generated by the membrane electrode assembly is absorbed by the coolant fluid. The preferred flow means comprises tubes or capillaries for containing the coolant fluid within the membrane electrode assembly. The preferred coolant fluids in this configuration are water and ethylene glycol.

Alternatively, cooling of the membrane electrode assembly may be accomplished by extending heat transfer surfaces or fins from the surfaces of the separator layers facing away from the membrane electrode assembly and flowing a coolant fluid across the heat transfer surfaces. Heat generated

separator layers.

FIG. 3A is an enlarged sectional view of the circled portion of the electrode of FIG. 3, having reactant flow grooves with coated side walls.

FIG. 3B is an enlarged sectional view of the circled portion of the electrode of FIG. 3, having reactant flow grooves with capillaries extending through the grooves.

FIG. 4 is a side view of a conventional (prior art) fuel cell repeating unit consisting of two membrane electrode assemblies and interposed between rigid separator plates, one of which contains coolant passages.

FIG. 5 is a side view of one embodiment of a fuel cell repeating unit consisting of two membrane electrode assemblies having integral reactant flow passages according to the present invention and interposed between two thin, lightweight separator layers, and a single-sided cooling jacket.

FIG. 6 is a side view of another embodiment of a fuel cell repeating unit consisting of two membrane electrode assemblies having integral reactant flow passages according to the present invention and interposed between three thin, lightweight separator layers, and a double-sided cooling jacket.

FIG. 10 is a plan view of a second embodiment of a cathode corresponding to the anode of FIG. 9 and formed of porous electrically conductive sheet material and having header grooves extending from the inlet and outlet associated with the respective oxidant inlet and outlet manifolds.

FIG. 11 is a plan view of a third embodiment of an anode according to the present invention and formed of porous electrically conductive sheet material and having branched, interdigitated grooves extending from the inlet and outlet associated with the respective fuel inlet and outlet manifolds.

FIG. 12 is a plan view of a third embodiment of a cathode corresponding to the anode of FIG. 11 and formed of porous electrically conductive sheet material and having branched, interdigitated grooves extending from the inlet and outlet associated with the respective oxidant inlet and outlet manifolds.

FIG. 13 is a plan view of a fourth embodiment of an anode according to the present invention and formed of porous electrically conductive sheet material and having a single, serpentine groove interconnecting the inlet and outlet associated with the respective fuel inlet and outlet manifolds.

FIG. 14 is a plan view of a fourth

continuous flow channels similar to those shown in FIGS. 13 and 14 (plot labeled "Y").

FIG. 17 is a composite of two polarization plots of cell voltage as a function of current density in a fuel cell repeating unit employing electrodes having integral reactant flow passages as shown in FIGS. 13 and 14, separator layers formed of .100 inch thickness graphite, using (1) oxygen-containing air as the oxidant stream (plot labeled "F") and (2) substantially pure oxygen as the oxidant stream (plot labeled "G").

DETAILED DESCRIPTION OF THE DRAWINGS

Turning first to FIG. 1 of the drawings, a fuel cell stack assembly 10 includes an electrochemically active section 26 and a humidification section 28. Stack assembly 10 is a modular plate and frame design, and includes a compression end plate 16 and a fluid end plate 18. An optional pneumatic piston 17, positioned within compression end plate 16, applies uniform pressure to the assembly to promote sealing. Bus plates 22 and 24 located on opposite ends of active section 26 provide the negative and positive contacts, respectively, to draw current generated by the assembly to a load (not shown). Tie rods 20 extend between end plates 16 and 18 to retain and secure stack assembly 10 in its assembled state with

and cathode 46. In conventional fuel cells, anode 44 and cathode 46 are formed of porous electrically conductive sheet material, preferably carbon fiber paper, and have planar surfaces. Electrodes 44 and 5 46 have a thin layer of catalyst material disposed on their surfaces at the interface with membrane 42 to render them electrochemically active.

As shown in FIG. 2, separator plate 34 has at least one groove 34a engraved, milled or 10 molded in its surface facing membrane electrode assembly 32. Similarly, separator plate 36 has at least one groove 36a engraved, milled or molded in its surface facing membrane electrode assembly 32. When assembled against the cooperating surfaces of 15 electrodes 44 and 46, grooves 34a and 36a define the reactant flow field passages for the fuel and oxidant, respectively. Grooves 34a and 36a are each preferably a single continuous groove interconnecting the inlet and outlet manifolds (not 20 shown) for the fuel and oxidant supplied to fuel cell 30, as described in U.S. Patent No. 4,988,583, incorporated herein by reference. Grooves 34a and 36a could also be engraved, milled or molded as a plurality of separate grooves interconnecting the 25 respective fuel or oxidant inlet and outlet manifolds.

Turning now to FIG. 3, a fuel cell 50 employs a membrane electrode assembly 52 having

interstitial spaces within electrodes 64 and 66 serving as the reactant flow passages for the fuel and oxidant streams, as well as for the removal of reaction product.

5 FIG. 3A is an enlarged sectional view of the circled portion of the electrode 64 of FIG. 3, in which the two side walls of reactant flow grooves 64a are coated with a sealant layer 65 that is substantially impermeable to the reactant
10 flowing through grooves 64a. The presence of sealant layer 65 directs the flow of reactant toward the catalyst layer (not shown in FIG. 3A) through the bottom wall 63 of grooves 64a to avoid the short circuiting of the reactant flow between
15 adjacent grooves.

 FIG. 3B is an enlarged sectional view of the circled portion of the electrode 64 of FIG. 3, in which capillaries 67 for carrying reactant extend within grooves 64a. Capillaries 67 contain
20 openings (not shown) formed along their length at periodic intervals to permit the flow of reactant into electrode 64 and toward the catalyst layer (not shown) at which the electrochemical reaction occurs. Capillaries 67 can be continuous (i.e.,
25 extending the entire length of the groove between the inlet and the outlet) or discontinuous (i.e., extending along only a portion of the groove), depending upon the efficiency of reactant flow

surface of cathode 86, and for the removal of reaction product formed at cathode 86. The other surface of MEA 80 cooperates with grooves 104b to define the reactant flow passage for carrying the fuel stream along the principal surface of anode 84. Similarly, the surface of MEA 90 cooperates with grooves 104a to define the reactant flow passage for carrying the oxidant stream along the principal surface of cathode 96, and for the removal reaction product formed at cathode 96. The other surface of MEA 90 cooperates with grooves 106b to define the reactant flow passage for carrying the fuel stream along the principal surface of anode 94. The blank surface 106a of plate 106 cooperates with grooves 102b in the adjacent fuel cell repeating unit (not shown) to form the passage for carrying the coolant stream. As such, plate 102 is also referred to as the cooling jacket.

FIG. 5 illustrates a first embodiment of a fuel cell repeating unit 110 consisting of two membrane electrode assemblies 120, 130 having integral reactant flow passages according to the present invention and interposed between two thin, lightweight separator layers 142, 144 and a single-sided cooling jacket 146. MEA 120 is substantially identical in configuration to MEA 52 of FIG. 3, and includes an ion exchange membrane

fu 1 stream within anode 124. On its opposite surface, separator layer 142 cooperates with grooves 136a to define the reactant flow passages for carrying the oxidant stream within cathode 136, and for removing reaction product formed at cathode 136. The surface of thin, lightweight separator layer 144 cooperates with grooves 134a to define the reactant flow passage for carrying the fuel stream within anode 134. On its opposite side, separator layer 144 cooperates with grooves 146a to form the passage for carrying the coolant fluid within single-sided coolant jacket 146. The opposite surface 146b of coolant jacket 146 is blank (ungrooved), and cooperates with grooves 126a in the cathode 126 of the adjacent fuel cell repeating unit (not shown) to define the reactant flow passages for carrying the oxidant stream within cathode 126.

FIG. 6 illustrates a second embodiment of a fuel cell repeating unit 210 consisting of two membrane electrode assemblies 220, 230 having integral reactant flow passages according to the present invention and interposed between three thin, lightweight separator layers 240, 242, 244 and a double-sided cooling jacket 246. MEA 220 is substantially identical to MEA 120 of FIG. 5, and includes an ion exchange membrane 222 interposed between an anode 224 having integral grooves 224a

grooves 246b of coolant jacket 246 to form the passages for carrying an additional coolant stream within coolant jacket 246.

FIG. 7 shows a first embodiment of an
5 anode 260 having integral reactant flow passages for the fuel (hydrogen) stream. Anode 260 is formed of porous electrically conductive sheet material 262 having a plurality of openings formed therein. The openings align with corresponding
10 openings in adjoining electrodes and separator layers to form the manifolds for carrying the hydrogen, oxidant (oxygen-containing air) and coolant (water) streams within the fuel cell stack. The openings in anode 260 include dry
15 (unhumidified) hydrogen inlet manifold 268, humidified hydrogen inlet manifold 270, humidified hydrogen outlet manifold 272, dry (unhumidified) air inlet manifold 274, humidified air inlet manifold 276, and humidified air outlet manifold
20 278, water inlet manifold 280, water-to-humidifier manifold 282, and water outlet manifold 284. Locator or alignment pin openings 286 are also formed in anode 260, as shown in FIG. 7. Humidified hydrogen inlet manifold 270 has an inlet
25 runner 264 for conducting the hydrogen fuel stream from manifold 270 to within the interstices of anode sheet material 262. Similarly, humidified hydrogen outlet manifold 272 has an outlet runner

within air outlet manifold 278. The humidified oxygen-containing air stream flows within the interstitial spaces of porous sheet material 292 between inlet runner 294 and outlet runner 296.

5 FIG. 8A shows the cathode of FIG. 8 with dam members 295 disposed within the porous electrically conductive sheet material 293. Dam members 295 disperse the flow of oxidant between the inlet runner 294 and the outlet runner 296, so
10 that the oxidant uniformly permeates and reaches the outer regions of sheet material 293, as opposed to being confined to preferential flow channels around the line connecting inlet 294 and outlet
15 296.

15 FIG. 9 shows a second embodiment of an anode 310 having integral reactant flow passages for the fuel (hydrogen) stream. Like anode 260, anode 310 is formed of porous electrically
20 conductive sheet material 312 having a plurality of openings corresponding to the openings described above for anode 260 in FIG. 7. Humidified hydrogen inlet manifold 270 has an inlet runner 314 and a header groove 318 extending from inlet runner 314
25 for conducting the hydrogen fuel stream from manifold 270 to within the interstices of anode sheet material 312. Humidified hydrogen outlet manifold 272 has an outlet runner 316 and a header
 groov 320 extending from outlet runner 316 for

material 352 having a plurality of openings corresponding to the openings described above for anode 260 in FIG. 7. Humidified hydrogen inlet manifold 270 has an inlet runner 354, a header groove 358 extending from inlet runner 354, and branched grooves 364 extending from header groove 358 for conducting the hydrogen fuel stream from manifold 270 to within the interstices of anode sheet material 352. Humidified hydrogen outlet manifold 272 has an outlet runner 356, a header groove 360, and branched grooves 362 extending from header groove 360 for conducting the fuel stream from within the interstices of anode sheet material 352 to within humidified hydrogen outlet manifold 272. Branched grooves 362 are interdigitated with branched grooves 364, as shown in FIG. 11. The hydrogen fuel stream flows between the individual branched grooves 362 and 364, and also between the header grooves and the neighboring branched grooves, within the interstitial spaces of porous sheet material 352.

FIG. 12 shows the embodiment of a cathode 370 corresponding to the anode 350 of FIG. 11. Cathode 370 is formed of porous electrically conductive sheet material 372 having a plurality of openings corresponding to the openings described above for anode 260. Humidified air inlet manifold 276 has an inlet runner 374, a header groove 378,

continuous serpentine groove 398 interconnects inlet runner 394 and outlet runner 396, and conducts the hydrogen fuel stream from inlet runner 394 to outlet runner 396.

5 FIG. 14 shows the embodiment of a cathode 410 corresponding to the anode 390 of FIG. 13. Cathode 410 is formed of porous electrically conductive sheet material 412 having a plurality of openings corresponding to the openings described
10 above for anode 260. Humidified air inlet manifold 276 has an inlet runner 414 extending therefrom, as shown in FIG. 14. Humidified air outlet manifold 278 has an outlet runner 416 extending therefrom, as shown. A single, continuous serpentine groove
15 418 interconnects inlet runner 414 and outlet runner 416, and conducts the oxygen-containing air stream from inlet runner 414 to outlet runner 416.

 FIG. 15 compares the performance of two individual fuel cells employing membrane electrode
20 assemblies having different integral reactant flow passage configurations to the performance of a fuel cell employing a membrane electrode assembly having conventional (ungrooved) electrodes and graphite
 flow field plates having single pass, continuous
25 flow channels similar to those shown in FIGS. 13 and 14. The fuel cells of FIG. 15 employed a Nafion 117 (.007 inch thick) ion exchange membrane, and were operated at a pressure of 30/30 psig

current densities beyond 120 amps per square foot. The conventional configuration of plot "X", with the reactant flow channels formed in the graphite plates, maintained higher voltage levels over a
5 broader current density range than either of the plot "A" or plot "B" configurations.

FIG. 16 compares the performance of three individual fuel cells employing membrane electrode assemblies having different integral reactant flow
10 passage configurations to the performance of a fuel cell employing a membrane electrode assembly having conventional (ungrooved) electrodes and graphite flow field plates having single pass, continuous flow channels similar to those shown in FIGS. 13
15 and 14. The fuel cells employed a Nafion 117 (.007 inch thick) ion exchange membrane, and were operated at a pressure of 30/30 psig air/hydrogen, a temperature of 72°C, and an air/hydrogen stoichiometry of 2.0/2.0. The fuel cells of FIG.
20 16 also employed graphite separator layers having a thickness of 0.20 inches. The electrodes were formed from 1.5 millimeter thick carbon fiber paper. Each of the fuel cells was interposed between two single-sided graphite cooling jackets.

25 The plot labeled "C" in FIG. 16 shows voltage as a function of current density (in amps per square foot) for the electrode configuration of FIGS. 7 and 8, namely, with the anode and cathode

configurations of plots "C", "D" and "E" each maintained higher voltage levels over a broader current density range than the conventional configuration of plot "Y", with the reactant flow channels formed in the graphite plates.

FIG. 17 shows the performance of two fuel cells employing membrane electrode assemblies having integral reactant flow passages and employing different oxidant streams. The electrodes in each of the fuel cells of FIG. 17 had a single, continuous serpentine groove milled in their surfaces facing away from the membrane, as shown in FIGS. 13 and 14. The fuel cells employed a Nafion 117 (.007 inch thick) ion exchange membrane, and were operated at a pressure of 30/30 psig oxidant/hydrogen, a temperature of 72C, and an air/hydrogen stoichiometry of 2.0/2.0. The electrodes were formed from 1.5 millimeter thick carbon fiber paper. The MEAs were interposed between blank, planar (ungrooved) separator plates formed of 0.100 inch thick graphite. Each of the fuel cells was interposed between two single-sided graphite cooling jackets.

The plot labeled "F" in FIG. 17 shows voltage as a function of current density (in amps per square foot) for the configuration employing oxygen-containing air (approximately 21% oxygen) as the oxidant. The plot labeled "G" in FIG. 17 shows

plates.

While particular elements and applications of the present invention have been shown and described, it will be understood, of course, that the invention is not limited thereto since modifications may be made by those skilled in the art, particularly in light of the foregoing teachings. It is therefore contemplated by the appended claims to cover such modifications and incorporate those features which come within the scope and spirit of the invention.

What is claimed is:

2. The electrochemical fuel cell of claim 1 wherein said flow means comprises the interstitial spaces within at least one of said first and second electrode layers.

3. The electrochemical fuel cell of claim 2 wherein at least one of said electrode layers further comprises dam members for diverting the flow of the reactant stream within said at least one electrode layer.

4. The electrochemical fuel cell of claim 2 wherein at least one of said electrode layers further comprises capillaries for containing the reactant stream within said at least one electrode layer along at least a portion of the distance between the inlet and the outlet.

5. The electrochemical fuel cell of claim 1 wherein at least one of said electrode layers has at least one groove formed in the surface thereof facing away from said membrane and the surface of the adjacent separator layer facing said electrode layer is substantially planar, whereby the surface of said electrode layer and the adjacent surface of said separator layer cooperate to define a passage for the flow of a reactant stream within said electrode layer.

output, said second groove discontinuous from said first groove, whereby said oxidant reactant stream flows from within said first groove to said second groove through the interstitial spaces of said second electrode layer.

11. The electrochemical fuel cell of claim 10 wherein said first groove and said second groove are branched, the branches of said first groove interdigitated with the branches of said second groove.

12. The electrochemical fuel cell of claim 1 further comprising a coolant layer adjacent at least one of said separator layers on the side opposite said membrane electrode assembly, said coolant layer formed of electrically conductive sheet material, said coolant layer comprising means for flowing a coolant fluid within said coolant layer, whereby heat generated by said membrane electrode assembly is absorbed by said coolant.

13. The electrochemical fuel cell of claim 12 wherein said coolant fluid is air.

14. The electrochemical fuel cell of claim 12 wherein said coolant layer has at least one groove formed in the surface thereof facing

20. The electrochemical fuel cell of claim 17 wherein said coolant fluid is ethylene glycol.

21. The electrochemical fuel cell of claim 1 wherein said separator plates include heat transfer surfaces extending therefrom and further comprising means for flowing a coolant fluid across said heat transfer surfaces, whereby heat generated by said membrane electrode assembly is absorbed by said coolant fluid.

22. The electrochemical fuel cell of claim 21 wherein said coolant fluid is air and said coolant flow means is a fan.

23. The electrochemical fuel cell of claim 1 wherein said electrode layers are formed of carbon fiber paper.

24. The electrochemical fuel cell of claim 1 wherein said separator layers are formed of a graphite composition.

25. The electrochemical fuel cell of claim 24 wherein said separator layers are formed of graphite foil.

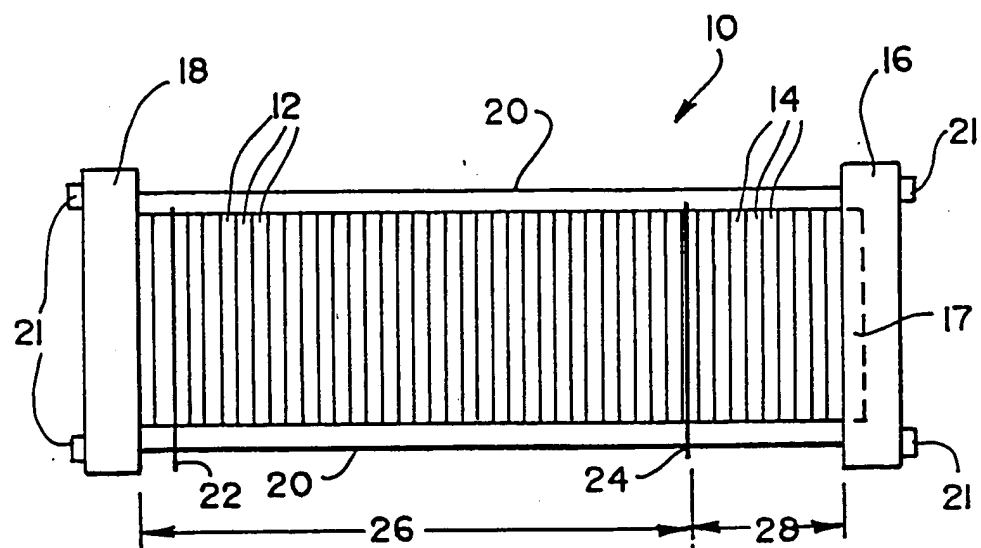
Fig. 1

Fig. 3A

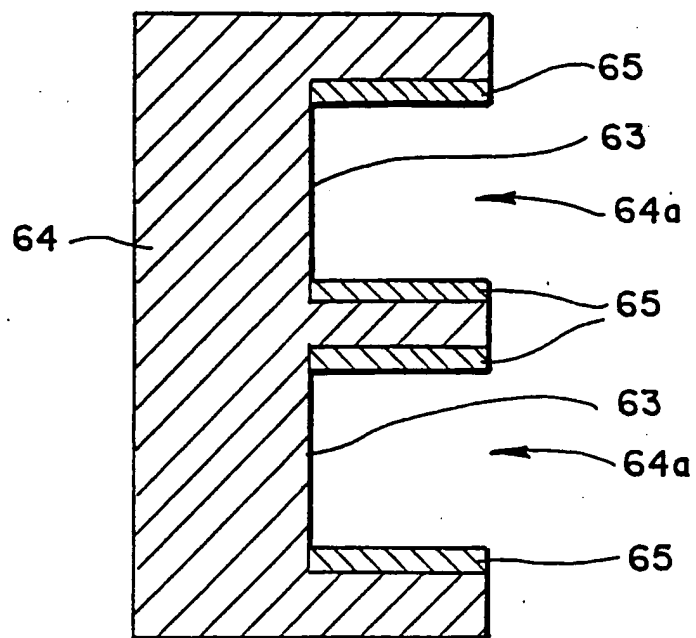
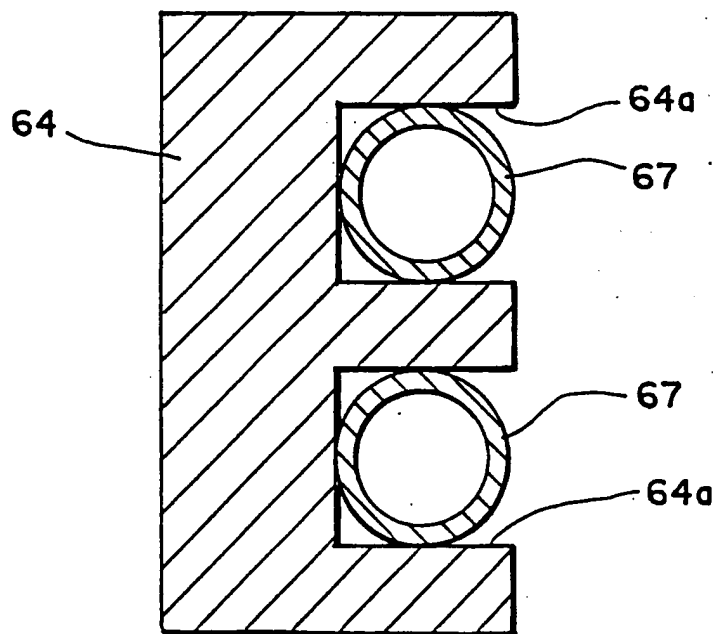


Fig. 3B



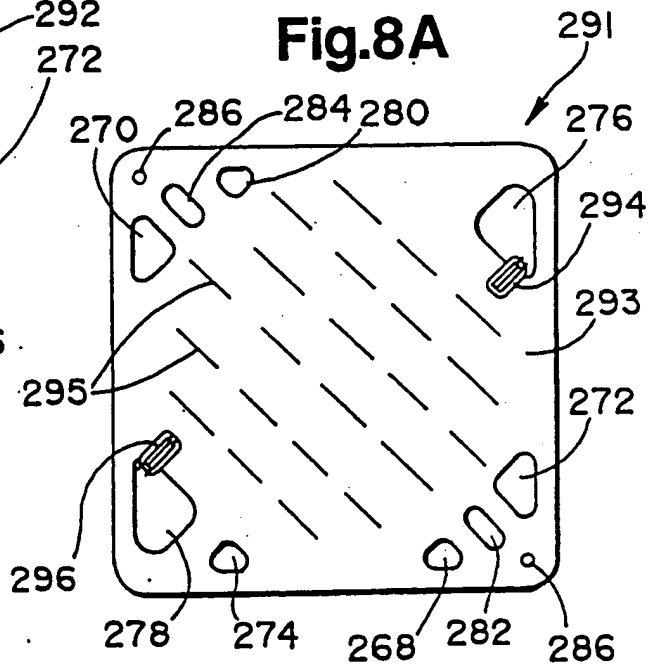
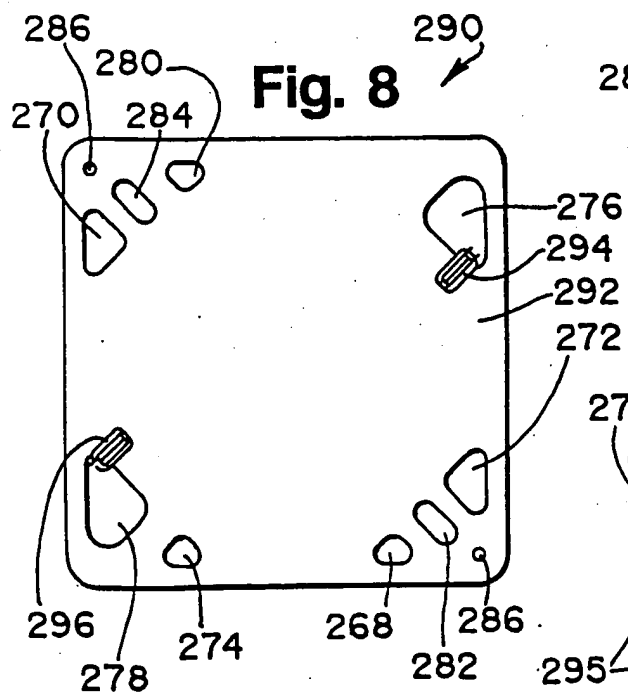
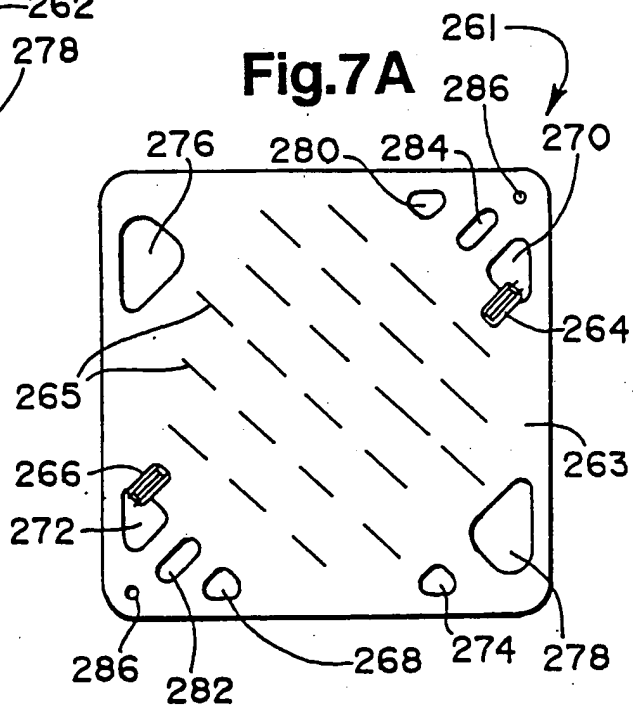
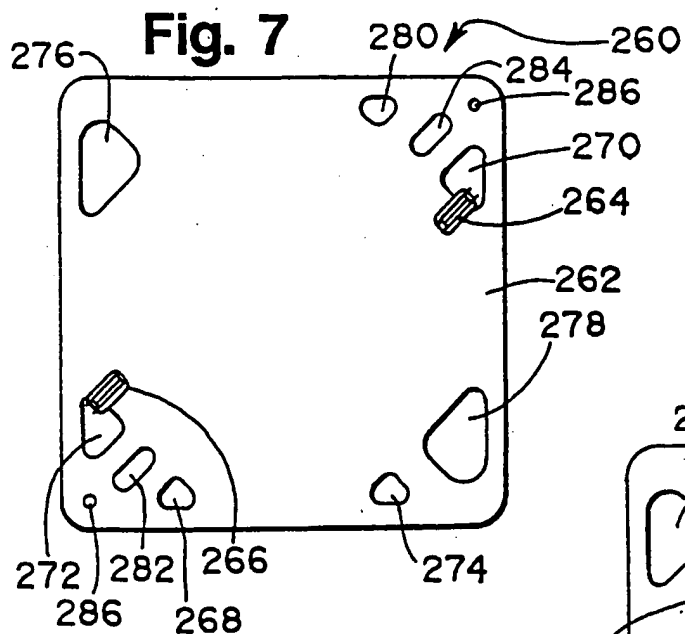


Fig.13

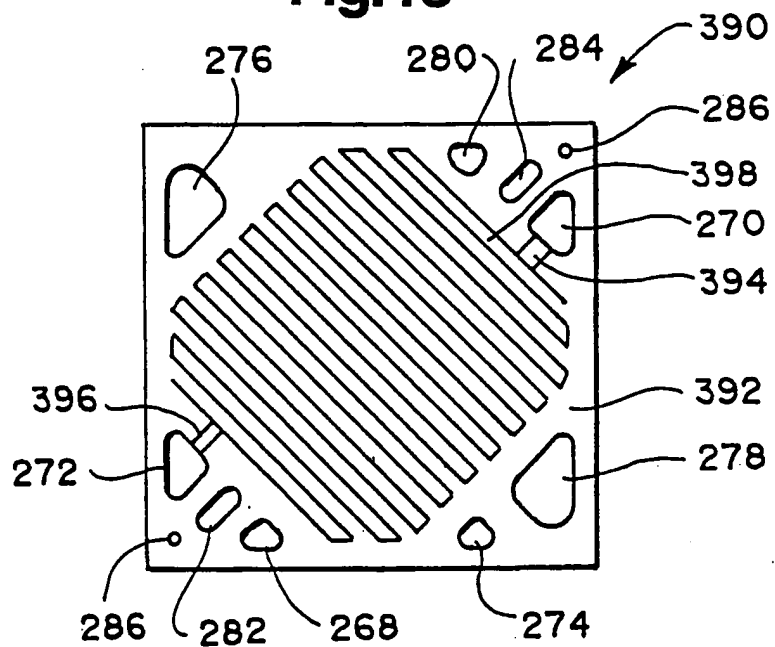


Fig.14

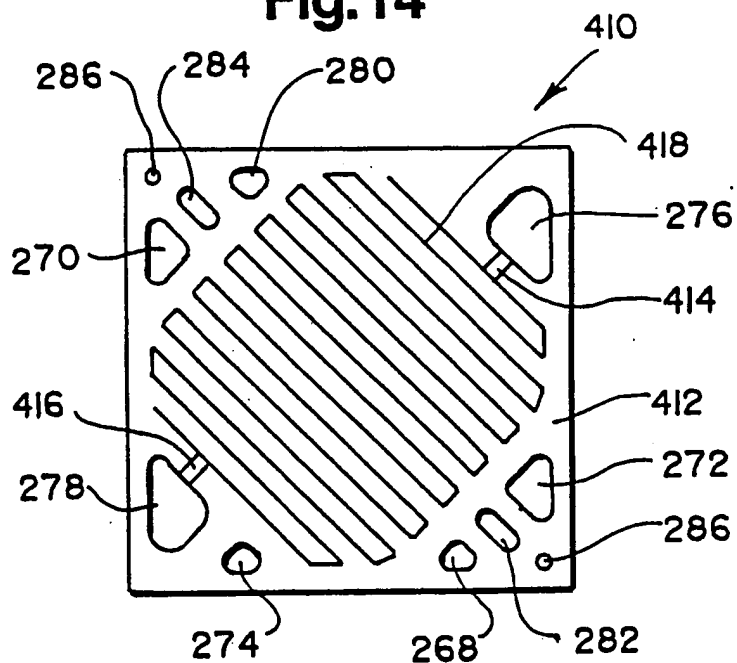
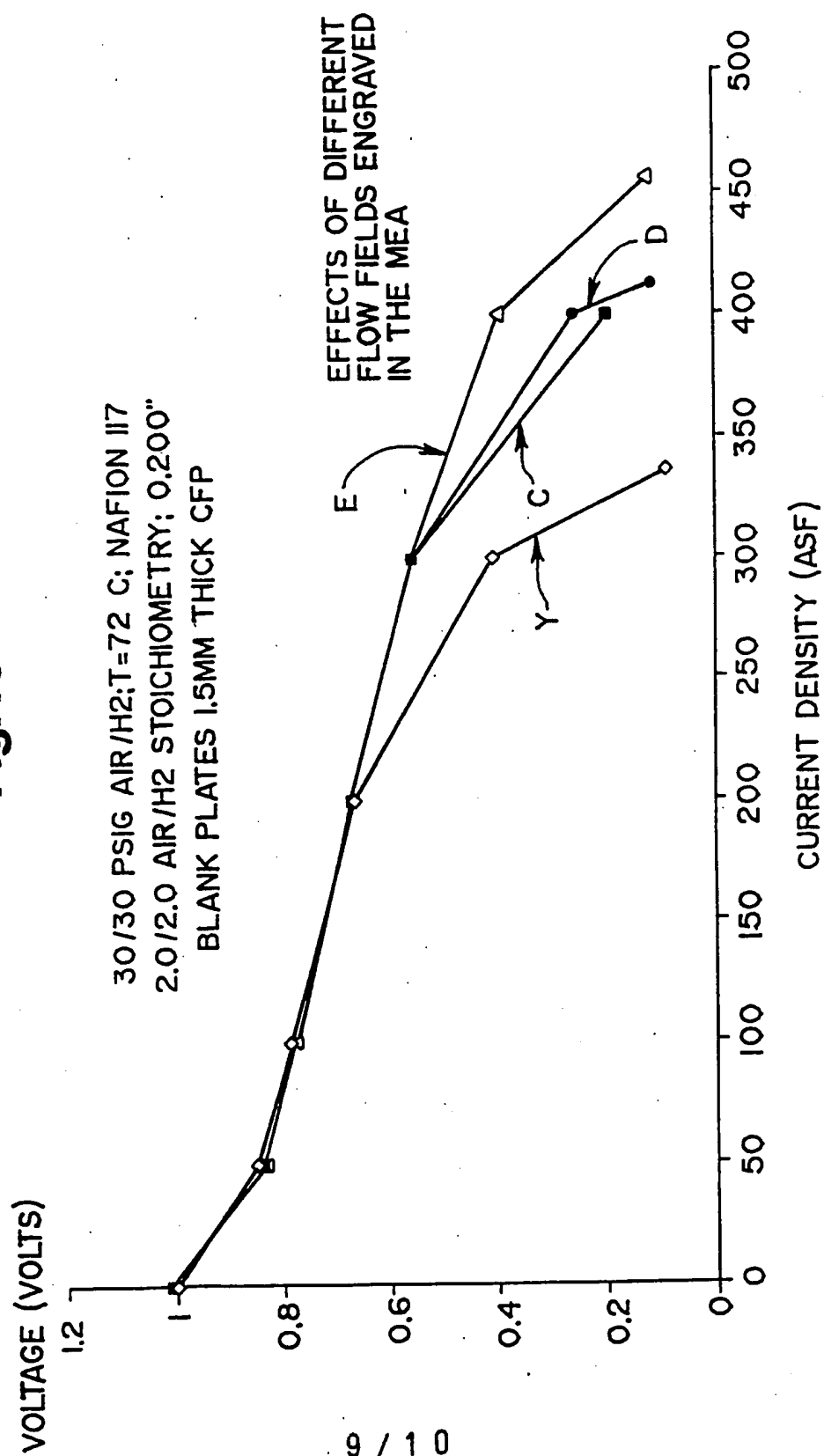


Fig.16

INTERNATIONAL SEARCH REPORT

PCT/US92/07755

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H01M 2/00

US CL :429/26,32,33,34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/26,32,33,34

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A, 4,977,041 (Schiowaza et al.) 11 December 1990.	1-31
Y	US,A, 4,929,517 (Luoma et al.) 29 May 1990.	1-31
Y	US,A, 4,826,741 (Aldhart et al.) 02 May 1989 See drawings.	1-31
A	US,A, 4,345,008 (Breault) 17 August 1982.	1-31
A	EP,A, 0080129 (Vum et al.) 01 June 1983.	1-31
Y	JP,A 0093268 (Seisakusho et al.) 28 July 1981 See Abstract.	1-31

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be part of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z*	document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means		
P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

30 DECEMBER 1992

Date of mailing of the international search report

15 JAN 1993

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